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No. 869.

THE REACTION BREAKWATER AS APPLIED TO THE IMPROVEMENT OF OCEAN BARS.

DISCUSSION.*

Mr. Wisner.

GEORGE Y. WISNER, M. Am. Soc. C. E. (by letter).—The ideal conditions for obtaining satisfactory results from a single curved jetty are usually found where the structure can be made a continuation of the natural curve of the outlet of the harbor entrance. The necessity of placing the jetty on the north side of the entrance at Aransas Pass makes a reverse curve of the channel, with a tendency to shoal at the "Crossing," and in order to maintain the full channel depth of 20 ft. between curves without dredging will probably require a spur jetty on the south side of the channel as far out as the wreck *Mary*.

Galveston Harbor, Cumberland Sound and Coatzacoalcos Harbor, Mexico, are good examples of natural conditions where a single curved jetty, properly located, would be certain to produce beneficial results. The Coatzacoalcas River is a silt-bearing stream, but the formation of the bar indicates that the load of sediment carried at times of floods is not sufficient to produce deposition from slight changes of velocity of current.

The formation of the west side of the entrance is also such that a single jetty constructed on the east side of the channel would practically control the river current in a restricted channel across the bar into deep water, and if the littoral current is from the eastward, as

* Continuation of the discussion on the paper by Lewis M. Haupt, M. Am. Soc. C. E., in *Transactions*, Am. Soc. C. E., Vol. xlii., p. 485.

Mr. Wisner. has been stated, a single curved jetty would be the proper remedy to apply.

It should be stated, relative to the fourth conclusion* that the limitation of the use of single jetties at the mouths of silt-bearing rivers is intended to apply only to such streams as the Mississippi and Brazos Rivers, where the load of sediment during freshets is such that any diminution of velocity of flow produces deposition.

The phenomena observed at the South Pass jetties, relative to the effect of curves and of outlets through jetties near the shore, have an interesting bearing on some of the conclusions brought out in the present discussion.

The Act of Congress, under which the South Pass jetties were constructed, requires the maintenance of a channel through the jetties 26 ft. in depth, not less than 200 ft. in width at the bottom, and having through it a central depth of 30 ft. without regard to width.

In 1888, the conditions in the Pass became such that, in order to maintain the legal channel, dredging was necessary during most of the time when such work could be done. The writer was employed to make the necessary improvements to prevent the periodic shoaling and narrowing of the channel, and, from a careful study of the situation, concluded that the deposit of sediment in the channel was due to breaks in the jetties, allowing a large amount of water to escape before reaching the end of the jetties, and that the curvature of the channel was such that excessive depths developed near the concave jetty and caused sufficient deposit on the convex side to reduce the width at a depth of 26 ft. to less than 200 ft.

The construction of spurs, or short wing-dams, along the face of the concave jetty at intervals of about 500 ft., checked the tendency of the convex bank to encroach on the channel, and the repairs of the breaks through the jetty walls stopped the excessive deposits, and fully justified the conclusion that the correct remedy had been applied.

During the construction of the jetties at the mouth of the Brazos River, a heavy freshet occurred when the east jetty was built above high water for its entire length, and the west jetty only about three-fifths of its final length, which resulted in scouring out a channel 25 to 30 ft. deep between the jetties, and built up the bar beyond the outer end of the west jetty, so that the depth was less than previous to the flood. Careful study of the phenomena at both the South Pass and Brazos channels indicates clearly that, unless the flood waters of the rivers are confined within the channels until discharged into the littoral current outside of the bar, navigable entrances cannot be maintained.

The amount of curvature given a channel fixes the width which can be maintained, and, if the curves be made sharp relatively to the

* See page 516, *Transactions*, Am. Soc. C. E., Vol. xlii.

volume of flow, sufficient width of channel cannot be maintained for the safe navigation of large vessels. Mr. Wisner.

Experience shows that deep channels are maintained easily along the concave sides of curves, and are deeper and nearer the bank as the curve is sharper.

The steepness and character of the banks also have much to do in fixing the depth and position of the deepest water relative to both sides of the channel. A steep smooth bank along the concave side of a curve, with a shore having a gentle incline toward the bed of the channel on the convex side, is best adapted for maintaining the ebb flow parallel to the concave bank with minimum curvature of the channel.

The results thus far obtained by the incomplete works at Aransas Pass indicate that the design and location of the structure is well adapted for developing such conditions.

J. Francis Le Baron, M. Am. Soc. C. E. (by letter).—The writer has been familiar with Professor Haupt's theories in regard to breakwaters since 1888, and is glad that an opportunity has arisen for testing them under such favorable circumstances. The writer uses the word favorable, because it seems to him that the conditions at Aransas Pass are peculiarly adapted to successful improvement with a single jetty, although while the old Government jetty remained, the harbor was effectively bottled up. Mr. Le Baron.

We have here at Aransas Pass a large sandbank on the windward side of the channel, which is unquestionably caused by the diagonal action of the waves under the strong Northers moving the sand down before them, until they reach the outflowing current of the Pass.

If this current were not there, the sands moving continuously, ever as a resultant of the diagonal waves, would speedily extend the shoal to Mustang Island and perfect the littoral cordon. Anyone who is familiar with the sea must have noticed that this diagonal action is present on nearly all beaches the greater part of the time. The reason is that, with the wind blowing from all points of the seaward semicircle, except the normal, and, perhaps, perfectly parallel to the littoral, or even a couple of points off shore, there are some 19 points of the compass which produce a resultant diagonal wave action with the ground swell always rolling in from the outer sea, which is operative in this case, not only whenever the prevailing winds blow, but with every sea breeze, except that which is dead on.

The marked effect of strong winds blowing diagonally to a long straight coast line is seen on the Florida east coast between Cape Canaveral and St. John's Bar.

With a stiff Norther blowing, the surface water is blown bodily along the beach inside the breakers to the southward; the broken and lumpy water offering a better hold for the wind, which creates a strong race in the shallow water. This results in piling up the water to the

Mr. Le Baron.

south, and, to restore the equilibrium, a strong counter-current is established just outside the breakers; and so it happens that whenever a Norther is blowing there is always a stiff current running up the beach in the face of the wind, which is very noticeable. The writer has observed the same thing on the north coast of Honduras during easterly winds, which are the prevailing winds in that locality. He has measured the velocity there and found it to be 1.04 miles per hour inside the breakers. This current was heavily charged with sand which was being constantly hurried to the westward and deposited on the spit on the east side of the mouth of the Patuca River, which in this way had been built out 400 ft. in eight years above water. If this spit could be induced to extend itself some 2 700 ft. it would form a perfect jetty, and this is what the writer proposes to do; to assist Nature by building the lightest jetty possible along the extension of the spit, which lies below water, so as to prevent the water from the harbor overflowing the crest of the spit and the sand from windward driving into the harbor; the spit will then be protected in its work of completing the littoral cordon.

Now, this is what has happened at Aransas Pass, where conditions appear to be quite analogous with the work being done at Patuca Bar. The jetty built by Professor Haupt has arrested the drive of sand to the southward and has prevented the escape of water over the rim of the north bank. Its curved shape has undoubtedly assisted the cutting out of the channel, for the reasoning of Professor Haupt on this point is not only logical, but is borne out by facts as we find them in all natural water-courses having any current, where, as every truant school boy can tell you, the deepest water is found in the bends, where he goes fishing.

This is caused by the revolving motion of the water, caused by the current striking the concave bank at an acute angle, and being guided by it in a circular path causing the formation of whirlpools which suck up the sand of the bottom, in the same manner that everyone has noticed a miniature whirlwind on a hot day, suck up in its vortex the bits of paper and dust in the street.

Thus far, the writer agrees entirely with the author, but is forced to differ from him on several other points. One of these is the little weight he is disposed to give to physical surveys and examinations; and here is shown the fallacy of leaving a breach in his wall to admit the flood tide near the shore. While the writer agrees with the author fully in the great and well-nigh imperative importance of the study of comparative charts, he cannot conceive how any permanent improvement of an ocean bar can be intelligently studied without the help of all the physical data which it is possible to obtain. These data, as the author observes, may sometimes seem conflicting and are often confusing, but it is the province of the engineer to so study and group them

as to harmonize or eliminate the apparent discrepancies and contradictions, which, on careful scrutiny, will generally be found to arise from imperfect or improperly directed examinations, wrong locations of observing stations, or abnormal conditions arising from unusual phases of meteorological or fluvial regimen. Mr. Le Baron.

It also often happens, as in the work upon which the writer is now engaged, that no previous survey of the locality has ever been made.

If we are to depend only on comparative charts, an engineer could lay out a system of improvement without ever going on the ground in person, which the writer thinks few practical men would care to undertake; but instrumental surveys, which the author condemns, are only more careful and extended personal observations, elaborated too much, perhaps, at times, but still only a method of arriving at facts which a simple visit cannot fully determine. Unless we know the direction and intensity of all the forces operating on an ocean bar at different points, how are we to estimate the effect of these forces, after the changes produced by our proposed works?

The study of charts alone, without surveys to determine the intensity and direction of the forces operating, is also misleading, when studied in plan alone, as volume is apt to be overlooked.

It would seem that the author has fallen into this error when he says:

"The effect of the two jetties is to invert the natural trumpet-shaped opening, and to diminish the area of the gorge, which is transferred to the crest of the bar, thus reducing the tidal volumes, preventing the complete filling of the interior compartment," etc.

The author likens the natural river mouth to a trumpet. A more accurate comparison would be made by considering the trumpet to be flattened until it represented a cubical sector. This sector has a depth, let us say, of 4 or 5 ft. When we narrow the opening over the bar we simply turn the sector on its edge and thus gain in depth what we lose in width. The cross-sectional area is practically the same as before.

The author speaks of preventing the complete filling of the interior compartment of the Pass, by the construction of converging jetties. The writer would like to ask him if he has ever seen any river mouth or pass which has been improved by converging jetties, the interior compartment of which failed to fill. We know that this has been prophesied often, but the writer has yet to find a case where the interior compartment failed to fill. It was feared that something of this kind might happen on the St. John's River, Fla., where converging jetties have been built, and upon which the writer was employed for several years as United States Assistant Engineer, but careful surveys and examinations, made by the United States Engineers after the jetties had been built, failed to show any diminution of volume.

Mr. Le Baron. It is admitted that jetties might be built so close together that almost no tide-water could enter, but in that case the river, or drainage, water from the surrounding water-shed would fill the compartment, which would be practically dammed up, with only a sluice-way between the jetties. This might happen while the works were in an unfinished state, before the jetty channel had acquired its contemplated normal depth, and the writer can see how we might easily raise the water level, but how we can lower it in the interior compartments he cannot see.

If we dredge and clear away all sand banks from the mouth of the river, or pass, and widen and deepen it, the low-water plane of the interior compartment may be lowered and the range of tide increased, but if we close up the mouth with a dam, which two jetties amount to, with a sluice-way between them, we will most certainly raise the water level in the interior compartments, and reduce the tidal range, just in proportion to the size of the sluice-way between the jetties. If, then, we raise the water level, we must have more water in the compartments, and the writer fails to see why fresh water is not just as good as salt water for navigation or for scouring.

Even where no river debouches through the jetties, and we have only a salt-water lagoon or harbor, the case would be rare indeed, where, taking a period of a year or several months, the effluent discharge did not exceed the influent. The reason for this is, that there is always a water-shed of greater or less extent to every harbor, and the writer ventures to say that Professor Haupt would never succeed in draining even a purely tidal basin by building a dam across it with an open sluice-way. Those who have had experience in draining tidal marshes know how difficult it is to accomplish this, even with tidal sluice-gates.

For these reasons the writer is utterly opposed to the plan of leaving an opening next the shore, or anywhere else, except in the jetty channel, for the admission of tide water. An opening through which the flood tide can enter permits more or less of the ebb tide to go out, and by just that much we lose scouring power in the ship channel, and are likely to set up a dangerous scour in the subsidiary channel, which may endanger the stability of the works, or bring an undesirable amount of sand into the harbor.

This problem is easily deduced by the *reductio ad absurdum*, for if a small channel is a good thing, a larger one is better. Then if we make it with the same cross-sectional area as our main channel, we will lose nearly if not quite the same amount of water, depending on the relative velocities, and so the scouring effect is reduced; for, in spite of the incident, quoted by the author, of the flood last summer on the Brazos not deepening the channel between the jetties at the mouth, we know that lessening the volume and velocity of discharge

produces bars and banks, which are swept away when floods come, and these cases are so well known and numerous as to require no demonstration. Mr. Le Baron.

If, then, instead of having two openings of say, the same width, with only 10 ft. depth each, we turn all the water through one of 20 ft. depth, the writer fails to see why the flood tide cannot find this opening and make as good use of it as is required. But the writer would prefer to keep all the flood tide out, if it were possible, and replace it with water of drainage or river water, even to the extent of creating a greater velocity between the jetties than might be desirable, which there would be some danger of doing if the mistake was made of making the channel too narrow.

This is a simple matter of computation, however, and it is the duty of the engineer to make it just right.

Leaving a jetty without any support, or with a gap between it and the shore, seems to the writer like sending a forlorn hope into an enemy's country unsupported. We are fighting the forces of Nature, and we must be careful and not be cut off from our reserves.

Another reason for leaving no gap in the line behind us is the ever-restless sand, which, as previously explained, is always traveling up or down the beach. If an opening is left here it deposits itself in the fair-way, but if the jetty is continuous to the shore the sand soon fills up the bight with a curved foreshore advanced to near the outer end of the jetty, backing and protecting the work, and rendering it indestructible by the waves.

For this reason, the jetty, in this position, can be very much less massive than would otherwise be necessary, and so the cost be reduced immensely and the river banks made continuous to the sea end.

This is what happened at the Suez Canal, Port Said; at St. Johns Bar, Fla., where the seaward angle of the south jetty filled up for over a quarter of a mile out; at Greytown jetty, Nicaragua; and what is sure to happen in every similar case on a sandy shore, where the prevailing winds blow along shore and into the bight made by the jetty.

The writer laid out the jetty at Greytown, making an angle of about 78° with the shore line to the eastward, from which quarter came the prevailing wind, and whence the sand was constantly moving along the beach. The location of this jetty was afterward moved quite a distance to the west, but the principle remains the same. In the writer's opinion, a large amount might have been saved in the cost of construction at Aransas Pass, if the jetty had been connected with the shore in the first place, as, although longer, it could have been much less massive and more secure, for Nature would then have been assisted in building up the foreshore, which would have formed a solid spit on the back or windward side.

Mr. Le Baron.

While the jetty at Aransas Pass has proved a success in securing deeper water, the writer does not believe that we can make a hard-and-fast rule, applicable to every bar. Each case must be studied with the help of all the data which can be obtained, and the success in this instance certainly does not warrant the author's sweeping condemnation of convergent or parallel jetties, which have been successful, as the author admits, at the Danube and Mississippi Rivers, at Tampico and also at St. John's River, Fla., Charleston, Newburyport, Galveston, Brazos River, the Swinemunde Haff, Germany, Volusia Bar, Lake George, and undoubtedly would have been at Cumberland Sound, which the writer laid out for General Gillmore, had it not been for the peculiar management of the work by Captain Carter.

At St. John's Bar the depth has been increased from 12 to 22 ft. At Volusia Bar, of which work the writer was in charge, first as engineer and later as contractor, the depth was increased from 4½ to 6 ft., all that was demanded by boats of the class navigating it. Many others might be mentioned.

Where dredging has been resorted to in connection with these jetties it has generally been done while the works were yet in an uncompleted state and to hasten the development of a deep channel at the instance of some impatient board of trade or meddling member of Congress. Sometimes it is rendered necessary, owing to the location of the jetties and the resulting jetty channel, as at St. John's Bar and at Greytown, where the new channel, in both cases, had to be cut through a sand bank 4 and 5 ft. above the water. At St. John's Bar the south jetty crossed the main ship channel, in order to make the resulting jetty channel take a more direct route to deep water outside the bar, and this channel had to be made through a large sand bank, known as Ward's Bank, which was dry at high water and nearly 6 ft. above low water; otherwise the north jetty would have had to be more than double its present length. It is a question if it would not have been cheaper, in the end, to have followed the natural channel, in this case, and assisted Nature to deepen it. After all, in all bar improvements, the main thing is the location of the jetties, and it is always safest to follow and assist Nature, when possible. This is shown, in the case under consideration, by the location of the old Government jetty, which was a flagrant example of wrong location, as it was built to leeward of the proposed channel, leaving it entirely unprotected from the encroaching sands to windward, with the result that it failed entirely to produce the desired results.

The use of curved, instead of straight, jetties is not new, as is well known. Here we have two jetties, both curved, but one properly located and the other improperly. The old Government jetty is evidently an attempt to follow the plan adopted at Swinemunde Haff, below

Stettin, in Germany, where a curved jetty was built over 20 years ago, which has proved successful; but this jetty was built to windward of the channel, as it should be, whereas in the case at Aransas Pass the fatal mistake was made of building it to leeward. The fact that one jetty has been built here which has secured deep water does not prove that two jetties, if properly located, would not have produced the same, if not better, results; but if we can dispense with one of the jetties, and so save in cost, of course, it is preferable to do it. Mr. Le Baron.

The reason the author's jetty has succeeded and the Government jetty failed is, in the writer's opinion, entirely due to its location, and there is little doubt that a straight jetty in the same location would have produced the same results, as the main thing in this case was to protect the channel from the encroaching sands to windward. This done, Nature could safely be left to do the rest. In work of this kind we cannot cut out a pattern, lay it down on every chart of an ocean bar, and expect a jetty or breakwater built after it to open a channel, any more than we can take the locations, plans and profile of one railroad and use them for every other. Hardly any two cases can be treated exactly alike, but every one must be studied in detail, and with all the light of past experience and history to aid us in digesting and formulating all the facts obtainable in each particular case.

GARDNER S. WILLIAMS, M. Am. Soc. C. E. (by letter).—Although the writer can lay no claims to experience in the construction of jetties or the improvement of harbors, it has come in his way to study quite closely the action of water upon the surfaces which confine it, and it seems to him that the so-called reaction breakwater is the only practical application of the real forces of erosion in moving water which has been cited in the present discussion. Without intending to in any way show disrespect for the older members of the profession or wishing to be accused of partisanship, it must be said that the true and most effective cause of scour by water currents seems to have been almost entirely overlooked, even by so eminent an engineer as Captain Eads. Mr. Williams.

The flow of water in straight channels of regular cross-section is not likely to be accompanied by strong scouring action, even at quite high velocities, because the direction of the flow of the individual filaments of the water is tangential to the bounding surface, but let a curve of long radius be introduced and something quite different will occur. The point or region of maximum velocity will be disturbed and carried toward the convex side of the stream, and the resulting rearrangement of the velocities will produce something approaching a spiral motion in the water, which will not be for any considerable distance tangential to the bounding surfaces, and hence erosion will take place at once. If the curve be continued for a sufficient distance, the velocities rearrange themselves in conditions most closely conforming to their equilibrium and the scour diminishes, the direction

Mr. Williams. of the currents becoming again tangential. If, now, a tangent be introduced, the arrangement of velocities in the filaments is again disturbed and excessive erosion again sets in, to disappear once more when they have again arranged themselves. The success of the reaction breakwater lies in the fact that it has set up these non-tangential currents, and the success of many double straight parallel jetties lies in the circumstances of their having received a stream from a tortuous river channel and forced it to straighten itself as it flows through them, thereby setting up the cross currents; while the failure of others of similar construction has been due to the circumstance that they received a stream already moving in comparatively straight lines, and have continued it in the same lines without setting up non-tangential currents. So, we should not expect that in the improvement of tidal harbors the passing of a volume of water in and out between straight parallel walls would produce any very great amount of scouring; but if it be passed along a curved surface, in and out, a continual setting up of eddy currents will be produced and the scouring accomplished. The writer, only a few days ago, had an opportunity of observing a current full of eddies moving stones half as large as a man's head, while a few hundred feet further on, the same water, with a lineal velocity twice as great, would not move stones the size of hens' eggs.

Mr. Corthell. E. L. CORTHELL, M. Am. Soc. C. E. (by letter).—The last paragraph of the paper refers to the channel at the mouth of the Brazos River, Texas, in which it is stated that, contrary to the expectations of increased depths by the great flood of July last, the sounding showed but 15 ft. in several places, "thus demonstrating the relative superiority of the principle of reaction by a single jetty."

From a newspaper clipping it is learned that the United States Assistant Engineer in charge of the surveying expedition at the mouth of the Brazos River, has reported to Captain Riche, U. S. Engineer, in charge of the Brazos District, that there is a depth of 18 ft. of water at mean low tide at the mouth of the river, and that this depth extends not only from the Gulf through the jetties, but to 500 ft. above the lighthouse, which is some distance inland. The works at the mouth of the Brazos River were built in reference to a datum plane of average flood tides; this would make the depth at mean high tide over 19.8 ft. A more recent survey by the Government Engineers shows that there is, throughout the entire length of the jetty channel, a minimum depth of 20 ft. at mean low water, 21.8 ft. at mean high water, the datum plane of the works.

The feature to which attention is particularly called by the writer is, that although the high water came in July last, and the channel at that time was deepened to 18 ft. at mean low water, it has maintained itself through the seven months intervening between that date and the date of the survey by the United States Engineer.

Mr. Wrotnowski.

A. F. WROTNOWSKI, M. Am. Soc. C. E. (by letter).—While the conditions at Aransas Pass, resulting from the construction of its disconnected reverse-curve breakwater, seem to have fulfilled in a measure the expectations of the Board of Engineers who planned it, much remains to be done before it can be accepted as a success in the improvement of tidal harbors.

The very essence of the jetty principle of concentration of the volume of water, whether it be tidal or fluvial, between parallel dykes, is at stake, in this so-to-speak experiment; and should it prove efficacious in all its features, the great reduction in cost alone would certainly recommend its adoption.

There is no doubt in the writer's mind that the curved trend of a breakwater or jetty adds materially to the forces for scour of the channel, over that of a straight jetty. The tendency of a moving body of water in a confined channel with an uneven and rough bottom will always cause eddies, and a crooked channel, more or less tending to cross and recross from side to side, making an irregular cross-section; but with a properly and regularly curved jetty the tendency of the volume of water is to "hug" the concave side of the channel.

The sectional area in a curve or bend of a stream, be it between jetties or in a natural water-way, is always greater than in reaches. This will always be the case in the whole length of the segment of the curve, and this applies equally to a channel in an open way, especially when it is guarded in its trend by a breakwater, as is the case at Aransas Pass.

The system of two tidal entrances or debouchures, as in this case, is especially applicable where tides are slight, as they are in the Gulf of Mexico, because, on account of the comparatively small tidal volume to be depended upon for scour, it is essential to secure all the volume possible to cause the required scour, and so this system may well be tried in such small tidal localities.

But at other points, for instance, on the Pacific, along the United States and Mexican coast, where the shores are very abrupt and defiant, and the tides rise much higher, it is doubtful if the system could be applied. For the port of Altata, State of Sinaloa, Mexico, the writer has had occasion to propose a single jetty for the maintenance of a given depth at the new entrance to this port, which was breached through the Peninsula about 10 miles south of Altata during the hurricane of November, 1896. The writer had then in contemplation a detached jetty, but after having made the surveys he found the conditions not adapted, principally on account of very unstable and deep shores. He found, also, that the volume passing in and out was sufficient to accomplish the required scour and keep a permanent depth; therefore, a single curved jetty was proposed. The Government, however, was not ready to expend the required funds for its construction until a better financial condition was apparent.

Mr. Wrotnowski.

The auxiliary tidal mouth in the Aransas Pass work is open to question as to whether it is an advantage. During high wave-energy, there will likely be brought into the channel quantities of sediment which will deposit to the lee, and which, during storms of long duration, will accumulate in such quantities as to cause much delay afterward in clearing the channel of such deposition, by the disturbed forces operating in the channel.

The writer has seen considerable such deposition through breaches, especially at Tampico and Vera Cruz; in one case, at the last-named place, where it filled a radial space of about 300 ft. to a depth of 20 ft., and it covered entirely the inside apron of the breakwater for over 500 ft. Not only did it deposit, but it kept on accumulating in the harbor for a time, causing excessive expense in dredging, until the breaches were closed. It is true, however, that in this case there was not sufficient tidal energy inside the harbor to carry away such deposit.

At Tampico the case was different, and the deposition which took place there was readily swept away, the conditions therefor being favorable.

Mr. Haupt.

LEWIS M. HAUPT, M. Am. Soc. C. E. (by letter).—Mr. Wisner cites an ideal case for the use of such a breakwater, but, unfortunately, it was in consequence of the effort to apply this ideal by "continuing the natural curve of the outlet" that caused the work of the Government to fail at Aransas, for the reason that the "natural curve" is the result of the external drift encroaching upon the advancing or convex side of the inlet, and is therefore on the far or wrong side of the channel. A jetty built on the concave side, therefore, deposits the littoral drift in and blocks up the channel, causing the bar to move more rapidly seaward. Hence, it is not generally good practice to continue the "natural curve" without an auxiliary structure abreast of it to arrest the drift, thus requiring two jetties if the far one is built first.

As several members appear to be under the impression that the single curved breakwater is not applicable to the mouths of sediment-bearing rivers, the writer desires to state his reasons for entertaining a different opinion. The objection is based upon the statement "that any diminution of velocity of flow produces deposition."

This is conceded as correct on general principles, but subject to the modifications as to effects of velocity in producing scour, as noted by the writer and confirmed by Professor Williams, and Mr. Wisner in his former papers. Hence, the only question arising is as to which form of construction produces the greater diminution of velocity, one curved jetty or two straight ones; and are their effects upon the outflowing currents at all similar?

The writer's position as to two rigid jetties which are practically parallel is, as already stated, that they act merely as an aqueduct to convey the effluent water and its load of sediment over the site of an

existing bar merely to be deposited in the sea beyond, where a new obstruction will be formed, unless there is a strong littoral current to prevent it. A single reaction jetty, on the contrary, produces a lateral movement of sediment, thus removing it from the concave side where the velocity is the greatest, because of the longer path, and notwithstanding the lesser slope, to the convex side, where it accumulates and forms a natural levee, which, in process of time, automatically adjusts itself to variations of the regimen of the stream. It thus happens that instead of all the material being carried or rolled to the mouth, as with two jetties, by far the greater portion of it is thrust aside before reaching the outer end of the concave jetty and is deposited outside of the navigable channel, and thus the growth of the bar seaward is greatly retarded. The result is that the one jetty not only costs far less to build, but is also much cheaper to maintain. Mr. Haupt.

These views appear to be sustained by the facts stated by Mr. Wisner, relative to the maintenance of the Eads Jetties at the South Pass of the Mississippi River, authorized in 1875, at an estimated cost of $5 225 000. These jetties were parallel and 1 000 ft. apart—too far, in fact, for the best results from the small portion of the discharge traversing that effluent—but being rigid, the readjustment could only be made by groins and inner jetties which contracted the channel to about 600 ft., thus increasing the cost, and at the same time producing alternations of velocity instead of uniformity, but resulting finally in securing the 30 ft. of depth desired.

Mr. Wisner, however, makes an important statement, viz.: "That the curvature of the channel was such that excessive depths developed near the concave jetty and caused sufficient deposit on the convex side to reduce the width at a depth of 26 ft. to less than 200 ft.," thus showing that the degree of curvature was excessive, since the reaction was too great for the contracted channel; also, that there was a resultant movement of material from the concave to the convex bank. The channel through the South Pass has several reversals of curvature and consequent "crossings," yet the depths are maintained. The east or concave jetty* was located as a transition curve starting from a tangent, with a gradually increasing deflection until it reached a radius of 11 720 ft.; its total length being 12 100 ft., nearly 2½ miles. The west jetty was parallel to the other for nearly 3 000 ft., and thence to sea it curved with a radius of 15 000 ft.

Mr. Wisner states a fundamental principle when he says: "The amount of curvature given a channel fixes the width that can be maintained." Hence, the success or failure of the engineer depends upon a proper adjustment of his radii to the local conditions; if too short, the channel will be too deep and narrow, and *vice versa*. The happy medium which is best adapted to all stages must be determined.

* "The Mississippi Jetties," by E. L. Corthell, M. Am. Soc. C. E., p. 75.

Mr. Haupt. Hence, the writer is of the opinion that a single curved jetty, adjusted to the regimen of the stream, and having no restraining counter jetty to interfere with the natural deposition of material beyond the normal section of the channel, will not only cost less, but will give a far more satisfactory result as to maintenance.

In support of this view the writer submits a few brief extracts from well-known foreign authorities illustrating the action of curved channels. In his "Tidal Rivers" Mr. Wheeler says:

"A concave bank sets up a scouring action in the current by diverting the particles of the water from their straight course, causing that rotary motion and boring action which occurs in all bends, and which operates in deepening the channel along the concave side."

Mr. Stevenson says: "That it might safely be affirmed that a stream is most likely to follow a permanent course when directed by a concave bank."

Mr. Scott-Russell: "Where the curves were gentle, the natural bends should not be interfered with; that a river has an oscillating motion * * * the mere fact of the commencement of curvature would give it a tendency to continue that curvature, and the stream would go on oscillating regularly to the sea in curves of opposite curvature. Continuity of a system of oscillation should therefore be maintained."

Captain Culver says "that straight reaches are strictly to be avoided * * * since the deep-water track is acted upon by the most trifling causes, ranging from side to side at will * * * there is therefore no security whatever for the permanency of the deep water, either in a fixed channel or at the shipping berths."

The French Government Commission, in reporting on the improvement of the estuary of the Seine, advised that the training walls should be extended in a sinuous form, having a concave bend leading to the entrance to Honfleur Harbor, in order that deep water should be maintained at the entrance.

M. Fontain, in the rectification of the Rhine, avoided straight cuts and adopted curves.

From which it appears that the most experienced authorities recognize the value of curvature as a means of creating and preserving a channel in silt bearing, tidal streams and estuaries.

From all of which it would appear that for tidal estuaries or inlets on sandy coasts, where drift and wave bars obstruct the entrance, a single reaction breakwater should be placed to leeward of the proposed channel; while for sedimentary or delta rivers emptying into comparatively tideless seas, a single concave jetty, of long radius adjusted to the discharge, will best serve to create and maintain the best channel at least cost.

The cases are widely different, in consequence of the origin and direction of movements of the silt; the one being littoral and external, the other fluvial and internal; hence they require distinctively different treatments.